MULTIMEDIA UNIVERSITY

STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 3, 2016/2017

EMF4086 – RF TRANSISTOR CIRCUIT DESIGN

(ALL SECTIONS)

26 MAY 2017
3.00 p.m - 5.00 p.m
(2 Hours)

INSTRUCTIONS TO STUDENT

1. This question paper consists of 9 pages with 4 questions only.
2. Answer **ALL FOUR** questions, all questions carry equal marks of 25. The distribution of the marks for each question is given.
3. Please print all your answers in the Answer Booklet provided.
4. Useful formulae are listed in Appendix.

Question 1

(a) Explain briefly about the parameter transition frequency (f_T) for a bipolar junction transistor (BJT) and its physical significance.

[4 marks]

(b) Table Q1 lists a few commercial bipolar junction transistors (BJT) and their properties. Suppose that we wish to design a Class-A amplifier with the following constraints:

- Minimum output power of 20 mW into 50 Ω load
- Operating frequency of 900 MHz to 960 MHz.
- Power supply of 6 V to 9 V.

Suggest a suitable transistor to be used in the amplifier circuit. Support your choice with a short argument. *Note: the f_T is actually dependent on dc biasing conditions, and this is not shown in Table Q1 due to space constraint.*

[8 marks]

Table Q1

Device Part No.	Type	Package	$f_{T(typ)}$ /GHz	$V_{CE(max)}$/V	$I_{C(max)}$/mA	$h_{FE(min)}$
MMBT3904	NPN	TO-92	0.3	40	100	30
BFT25	NPN	SOT-23	1.2	5	25	25
BFS17W	NPN	SOT-323	1.6	15	50	25
BFR106	NPN	SOT-23	5	15	100	25
BFR93	PNP	SOT-23	5	12	35	20
BFG590	NPN	SOT-143	5	15	200	50

(c) Briefly explain THREE (3) advantages of BJT transistors.

[6 marks]

(d) Provide an explanation on why the RF transistors in Table Q1 are mostly of NPN type.

[3 marks]

(e) Apart from BJT, list FOUR (4) other discrete active components that are suitable to be use in radio-frequency (RF) circuits such as amplifiers, mixers and oscillators.

[4 marks]

Question 2

(a) Define and illustrate with a suitable diagram the small-signal transducer power gain G_T, available power gain G_A, and power gain G_P of an amplifier. What is the condition for maximum gain, when $G_P = G_T = G_A$?

[8 Marks]

Continued...

(b) A microwave transistor amplifier has the following *S*-parameters (Z_o = 50 Ω) measured at 5 GHz.

$$S_{11} = 0.641\angle -171.3° = -0.634 - j0.097,$$
$$S_{21} = 2.058\angle 28.5° = 1.809 + j0.982,$$
$$S_{12} = 0.057\angle 16.3°, = 0.0547 + j0.0160 \quad \text{and}$$
$$S_{22} = 0.572\angle -95.7° = -0.0568 - j0.569.$$

(i) Define the terms *unconditional stability* and *conditional stability* for a transistor amplifier.

[4 Marks]

(ii) Calculate the Roulette stability factor k and Δ, and state the stability condition.

[3 Marks]

(iii) Determine the reflection coefficients for simultaneous conjugate match, Γ_{Sm} and Γ_{Lm}.

[6 Marks]

(iv) Calculate in decibel (dB), the maximum stable gain for this amplifier.

[2 Marks]

(v) Calculate in decibel (dB), the maximum transducer power gain for this amplifier.

[2 Marks]

Question 3

(a) Draw THREE (3) resistive negative feedback topologies each for both the Bipolar Junction Transistor (BJT) and Field Effect Transistor (FET) broadband amplifier.

[6 Marks]

(b) A two-stage power amplifier consisting of first stage pre-amplifier and second stage power amplifier for linear operation at 4 GHz, are to be designed. The input signal power is 0 dBm. The input and output power relationships for amplifiers **Amp_A** and **Amp_B** at 4 GHz, are shown in **Figure Q3(b)**. One will be used as pre-amplifier while the other will be the power amplifier.

(i) Determine the linear power gain, 1 dB gain compression, input and output power at 1 dB gain compression for **Amp_A**.

[4 Marks]

(ii) Determine the linear power gain, 1 dB gain compression, input and output power at 1 dB gain compression for **Amp_B**.

[4 Marks]

(iii) Which amplifier is suitable for the first stage? Explain your answer.

[2 Marks]

Continued...

(iv) Which amplifier is suitable for the second stage? Explain your answer.

[2 Marks]

(v) Calculate the power gain and output power obtained after the first stage.

[2 Marks]

(vi) Calculate the power gain, output power, input and output power at 1 dB gain compression obtained from this design.

[5 Marks]

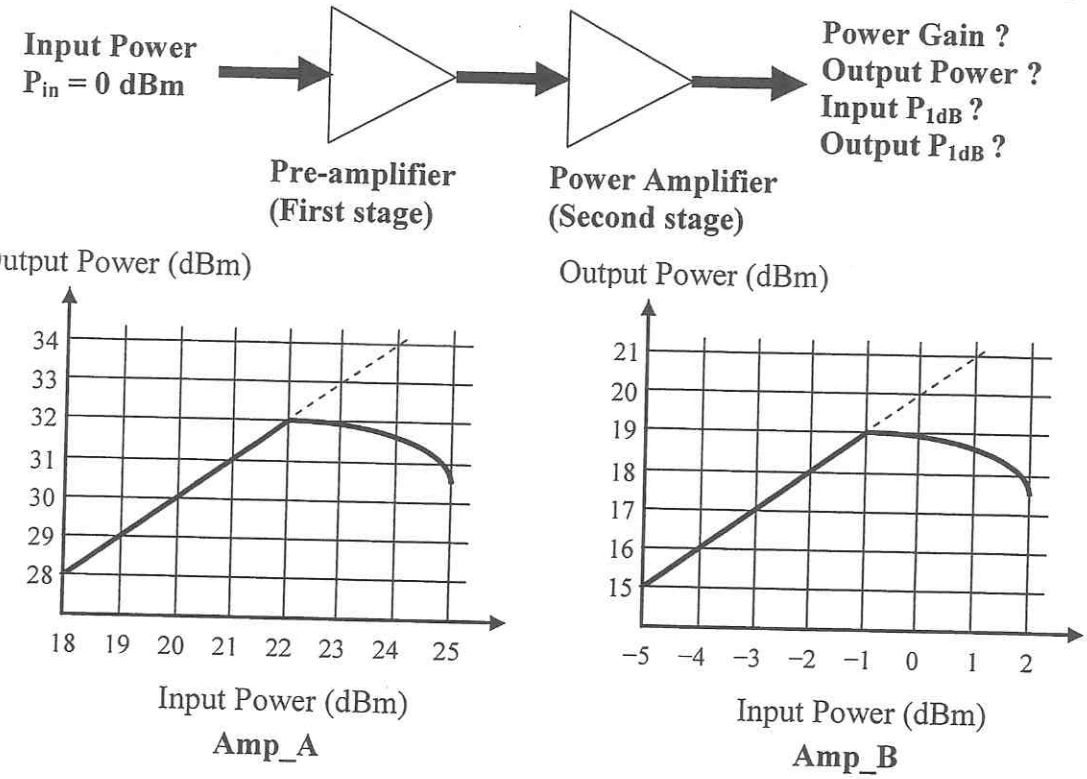

Figure Q3(b)

Question 4

The S – parameters of a GaAs FET in a common gate configuration is measured at 4.0 GHz and has the following values (Z_o = 50 Ω)

$$S_{11} = 0.72\angle -116° = -0.316 - j0.647,$$
$$S_{21} = 2.60\angle 76° = 0.629 + j2.522,$$
$$S_{12} = 0.03\angle 57° = 0.0163 + j0.0252,$$
$$S_{22} = 0.73\angle -54° = 0.429 - j0.591$$

(i) Calculate the Roulette stability factor k and Δ, and state the stability condition.

[3 Marks]

(ii) Can this transistor (in common gate configuration) be used as oscillator?

[2 Marks]

Continued...

In order to increase the instability, a lumped component is connected to the gate of the transistor as shown in **Figure Q4**. The new S – parameters of this configuration is measured at 4.0 GHz and has the following values ($Z_o = 50\ \Omega$)

$$S'_{11} = 2.18\angle -35° = 1.786 - j1.250,$$
$$S'_{21} = 2.75\angle 96° = -0.287 + j2.735,$$
$$S'_{12} = 1.26\angle 18° = 1.198 + j0.389,$$
$$S'_{22} = 0.52\angle 155° = -0.471 + j0.220$$

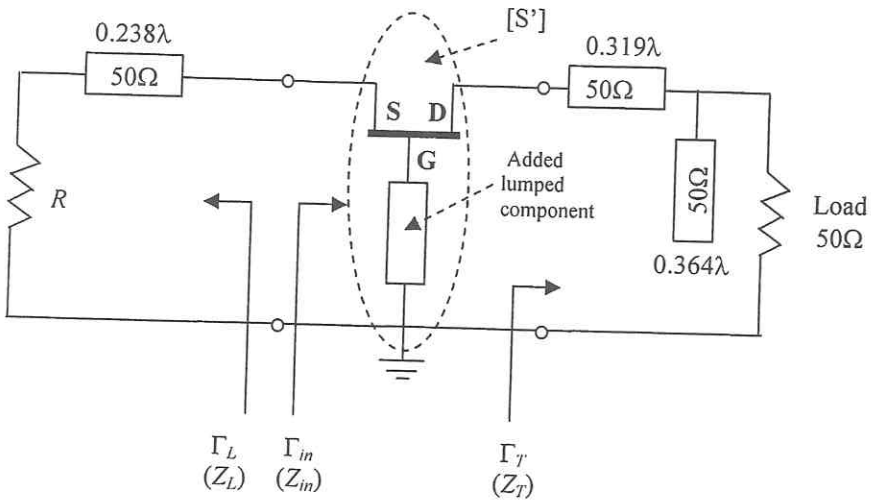

Figure Q4

(iii) What is the suitable lumped component added in this configuration?

[2 Marks]

(iv) Calculate the Roulette stability factor k and Δ, and state the stability condition.

[3 Marks]

(v) Can this configuration be used to design oscillator?

[2 Marks]

(vi) Calculate the center C_{out} and radius r_{out} of the output stability circle and plot this circle on the Smith chart and identify the stable and unstable regions. Suggest a load reflection coefficient, Γ_T that would satisfy the unstable operating condition of the oscillator.

[9 Marks]

(vii) With the suggested Γ_T, calculate Γ_{in} and Z_L.

[4 Marks]

APPENDIX

Given:

Input and Output reflection coefficient

$$\Gamma_1 = \Gamma_{in} = S_{11} + \frac{S_{12}S_{21}\Gamma_L}{1 - S_{22}\Gamma_L} \qquad \Gamma_2 = \Gamma_{out} = S_{22} + \frac{S_{12}S_{21}\Gamma_S}{1 - S_{11}\Gamma_S}$$

Power Gain, Available Gain and Transducer Gain

$$G_p = \frac{|S_{21}|^2\left(1 - |\Gamma_L|^2\right)}{\left(1 - |\Gamma_{in}|^2\right)|1 - S_{22}\Gamma_L|^2} \qquad G_A = \frac{|S_{21}|^2\left(1 - |\Gamma_S|^2\right)}{\left(1 - |\Gamma_{out}|^2\right)|1 - S_{11}\Gamma_S|^2}$$

$$G_T = \frac{|S_{21}|^2\left(1 - |\Gamma_S|^2\right)\left(1 - |\Gamma_L|^2\right)}{|(1 - \Gamma_S\Gamma_{in})|^2|1 - S_{22}\Gamma_L|^2}$$

Roulette stability factor

$$k = \frac{1 - |S_{11}|^2 - |S_{22}|^2 + |\Delta|^2}{2|S_{12}||S_{21}|} \quad and \quad \Delta = S_{11}S_{22} - S_{12}S_{21}$$

Output and Input stability circles parameters center and radius

$$r_{out} = \frac{|S_{12}S_{21}|}{\left||S_{22}|^2 - |\Delta|^2\right|} \qquad C_{out} = \frac{\left(S_{22} - S_{11}^*\Delta\right)^*}{|S_{22}|^2 - |\Delta|^2}$$

$$r_{in} = \frac{|S_{12}S_{21}|}{\left||S_{11}|^2 - |\Delta|^2\right|} \qquad C_{in} = \frac{\left(S_{11} - S_{22}^*\Delta\right)^*}{|S_{11}|^2 - |\Delta|^2}$$

Source & Load transmission coefficient for maximum gain (conjugate matching)

$$\Gamma_{Sm} = \frac{B_1 - \sqrt{B_1^2 - 4|C_1|^2}}{2C_1} \qquad \Gamma_{Lm} = \frac{B_2 - \sqrt{B_2^2 - 4|C_2|^2}}{2C_2}$$

$$B_1 = 1 + |S_{11}|^2 - |S_{22}|^2 - |\Delta|^2 \qquad C_1 = S_{11} - \Delta S_{22}^*$$

$$B_2 = 1 + |S_{22}|^2 - |S_{11}|^2 - |\Delta|^2 \qquad C_2 = S_{22} - \Delta S_{11}^*$$

Continued...

Low noise amplifier design parameters:

$$F = F_{\min} + \frac{4R_N}{Z_0}\frac{\left|\Gamma_S - \Gamma_{opt}\right|^2}{\left(1-\left|\Gamma_S\right|^2\right)\times\left|1+\Gamma_{opt}\right|^2} \qquad C_F = \frac{\Gamma_{opt}}{N+1}$$

$$R_F = \frac{\sqrt{N\left(N+1-\left|\Gamma_{opt}\right|^2\right)}}{N+1} \qquad N = \frac{F-F_{\min}}{4R_N/Z_o}\left|1+\Gamma_{opt}\right|^2$$

The center and radius of constant Power Gain Circle:

$$T_{G_P} = \frac{-g_2\,\mathrm{Re}(C_2)}{-1-\left|s_{22}\right|^2 g_2+\left|D\right|^2 g_2} + j\frac{g_2\,\mathrm{Im}(C_2)}{-1-\left|s_{22}\right|^2 g_2+\left|D\right|^2 g_2}$$

$$R_{G_P} = \frac{\sqrt{1-2K\left|s_{12}s_{21}\right|g_2+\left|s_{12}s_{21}\right|^2 {g_2}^2}}{\left|-1-\left|s_{22}\right|^2 g_2+\left|D\right|^2 g_2\right|} \quad \text{where} \quad C_2 = s_{22}-Ds_{11}^{\ *} \quad \text{and} \quad g_2 = \frac{G_P}{\left|s_{21}\right|^2}$$

The center and radius of constant Available Power Gain Circle:

$$T_{G_A} = \frac{g_1\,\mathrm{Re}(C_1)}{1+\left|s_{11}\right|^2 g_1-\left|D\right|^2 g_1} - j\frac{g_1\,\mathrm{Im}(C_1)}{1+\left|s_{11}\right|^2 g_1-\left|D\right|^2 g_1}$$

$$R_{G_A} = \frac{\sqrt{1-2K\left|s_{12}s_{21}\right|g_1+\left|s_{12}s_{21}\right|^2 {g_1}^2}}{\left|1+\left|s_{11}\right|^2 g_1-\left|D\right|^2 g_1\right|} \quad \text{where} \quad C_1 = s_{11}-Ds_{22}^{\ *} \quad \text{and} \quad g_1 = \frac{G_A}{\left|s_{21}\right|^2}$$

Cascaded 2-stage output power 1 dB gain compression:

$$P_{1dB} = \left[\frac{1}{P_{1dB_1}\times G_2} + \frac{1}{P_{1dB_2}}\right]^{-1}$$

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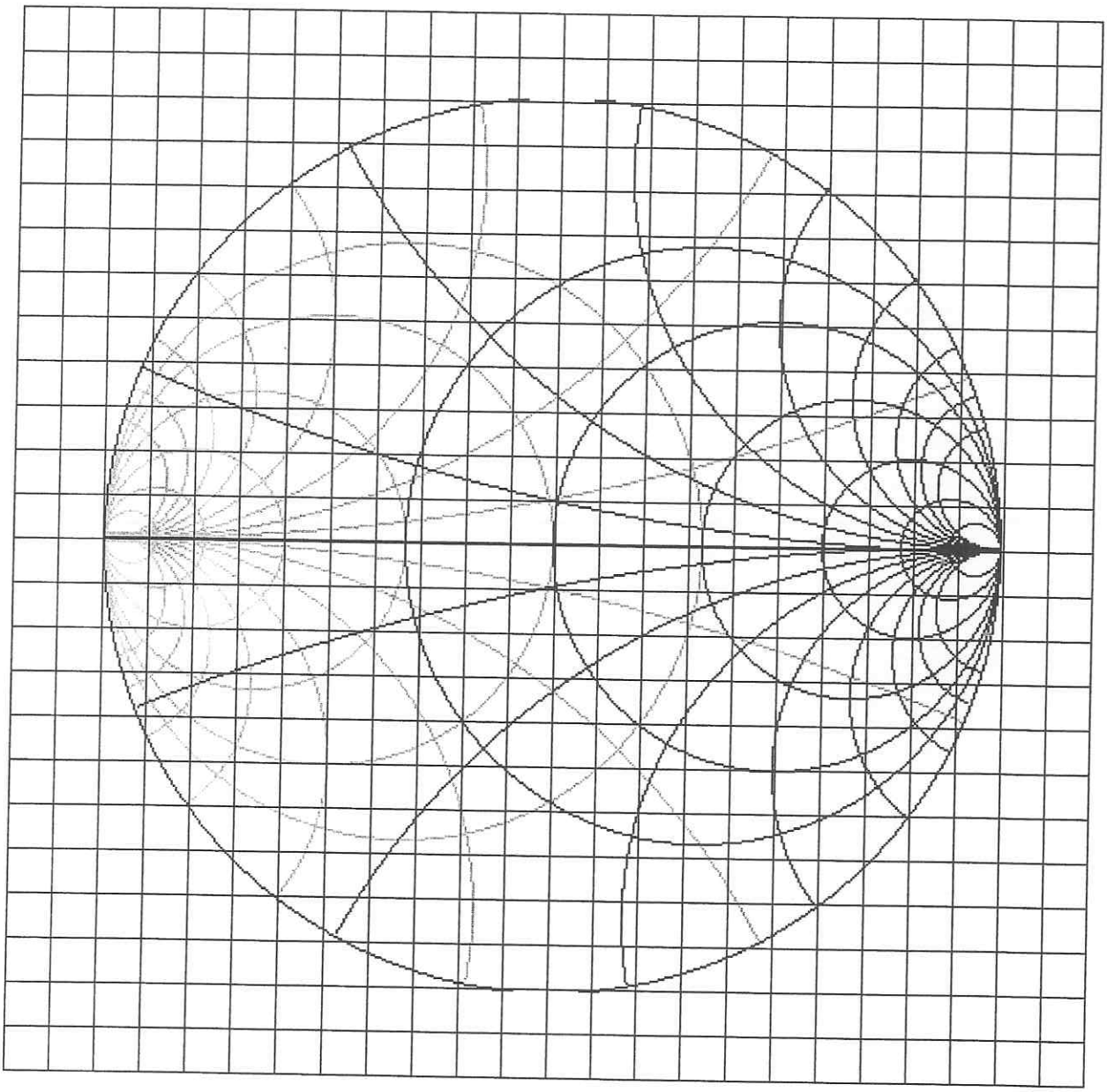

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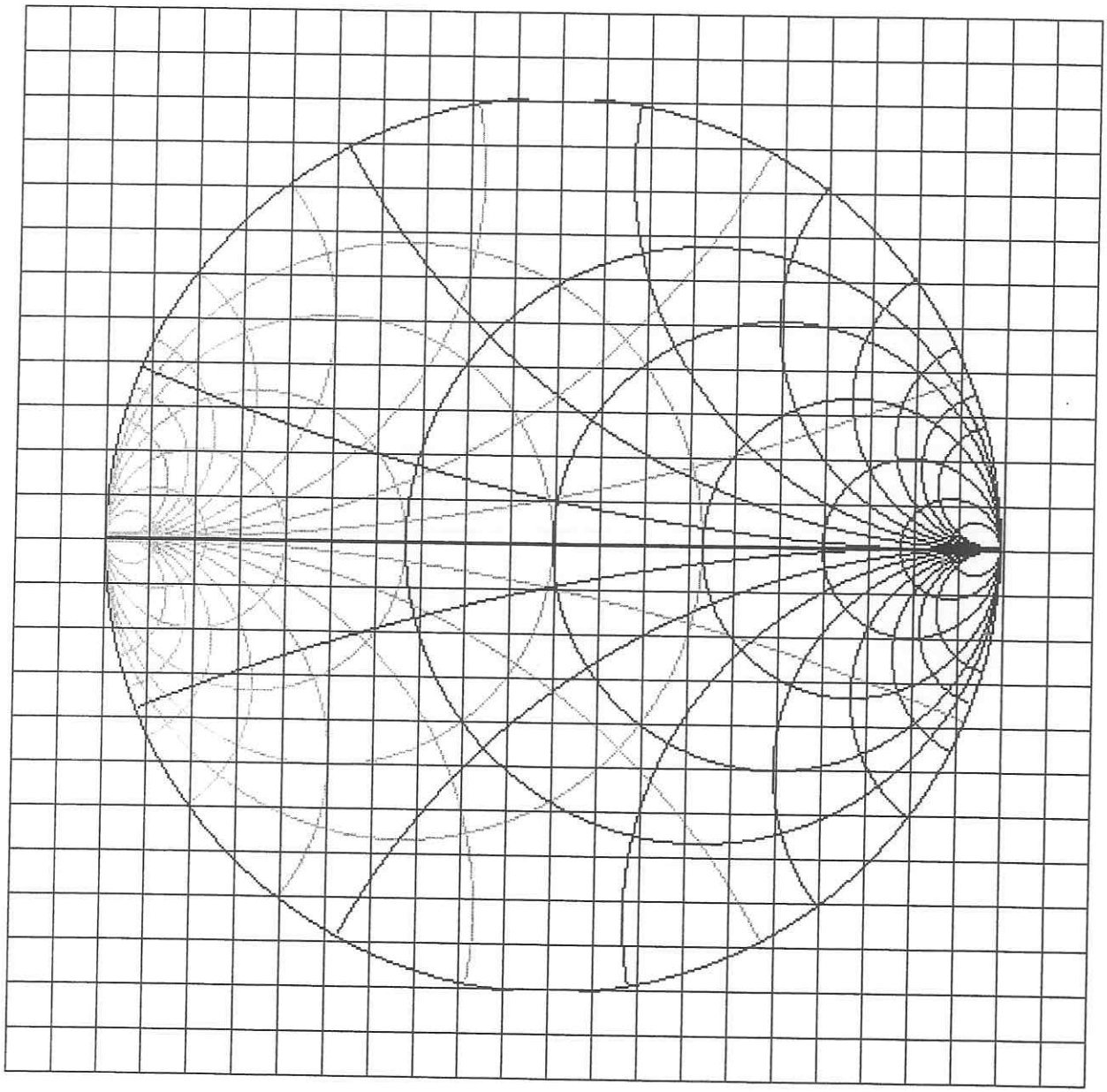

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